

Cumulative and Synergistic Effects of Physical, Biological and Acoustic Signals on Marine Mammal Habitat Use

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LONG-TERM GOAL

The long-term goal of this collaborative research effort is to enhance understanding of how variability in physical, biological and acoustic signals impact marine mammal habitat use. In particular, what are the effects of manmade underwater sound on marine mammal health and physiology, and what are the consequences of these effects at the marine mammal population level? A major component of this research is to use passive ambient sound to identify the physical environment present, and then to use this information to interpret the biological data collected. This report describes the passive component of this project.

OBJECTIVES

The objectives of the passive acoustic component of this collaborative research effort are to identify and make synoptic measurements of the physical environment that the marine mammals (whales and seals) are using. Attention to the physical environment is often absent from biological studies and yet is an important component of biological processes. Physical oceanographic processes, including wave breaking, rainfall and sea ice processes, all have distinctive acoustic signatures that can be used to detect, classify and quantify them. Learning to identify physical processes acoustically will be an important aid to more encompassing ecosystem studies. Furthermore, ambient noise levels in the Bering Sea are measured directly and provide a background baseline for future studies and operations. Long-term measurements will play an important role in determining the point at which cumulative effects of the environment and human activities impact animal populations, and in identifying the kinds of exposure that pose the greatest risk. The Bering Sea is an ecosystem that is presently experiencing rapid climate change, has relatively healthy populations of cetaceans and seals, and supports the largest fishery in the US EEZ.

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One especially interesting component of the Bering Sea ecosystem is that it is ice-covered for part of the year. Understanding how marine mammals interact with sea ice is particularly difficult to study as the environment is extremely difficult to sample by more traditional means such as ship cruises or maintaining surface moorings. In fact, NOAA does not attempt to maintain surface moorings during most of the year because of the threat of sea ice, and other harsh conditions. Acoustic sampling of this environment offers the possibility to extend measurements of the environment throughout the year.

APPROACH

This project is a three-year field study involving long-term monitoring of the physical and biological environment at two established NOAA mooring sites (known as M2 and M5) in the Bering Sea (Figure 1) (Stabeno and Hunt, 2002). An acoustic monitoring system using both active and passive acoustic sensors has been developed and deployed. The passive component is used to assess the physical environment and to detect and identify cetaceans and ice seals present near the moorings. The active component is used to investigate zooplankton distribution and abundance. Ancillary measurements of water column characteristics (temperature, salinity, nutrients, ice cover, etc.) will be available from the standard NOAA instrumentation on the moorings.

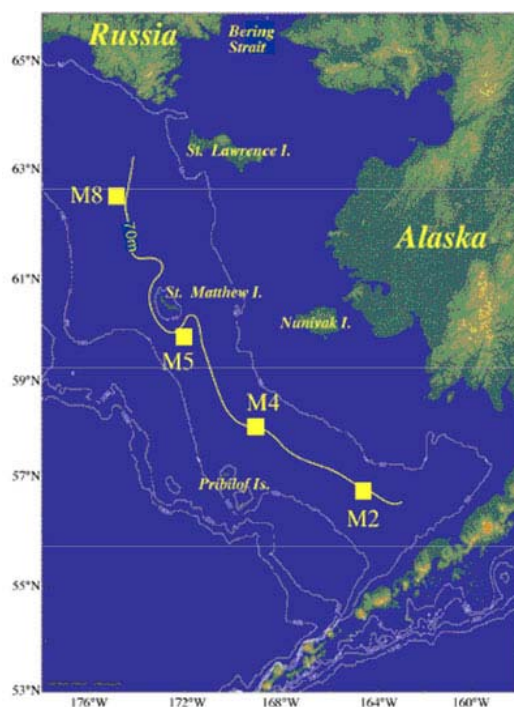


Figure 1. Map showing the location of the moorings (M2 and M5) maintained by NOAA that are being used for this project.

The component of the project that is associated with the passive acoustic monitoring of the environment is the specialty of Nystuen (APL/UW). The instrumentation used are Passive Aquatic Listeners (PALs), designed and developed at APL/UW. This report describes the use and interpretation of these instruments to support the objectives of this research project. This is the APL/UW component of this research effort.

PALs have been used for nearly a decade to quantitatively monitor the physical marine environment (Ma and Nystuen, 2005) (Fig. 2). They are not continuous recorders, but rather low duty cycle recorders that produce a time series of spectra, with an adaptive sampling strategy that allows different processes to be sampled differently when appropriate. One new feature is to record short temporal time series (4.5 seconds at 100,000 Hz sampling rate) that can be used to identify transient sounds such as calls and clicks from marine mammals. This feature has been used to detect and identify specific cetacean species, in particular, killer whales (Nystuen et al. 2007).

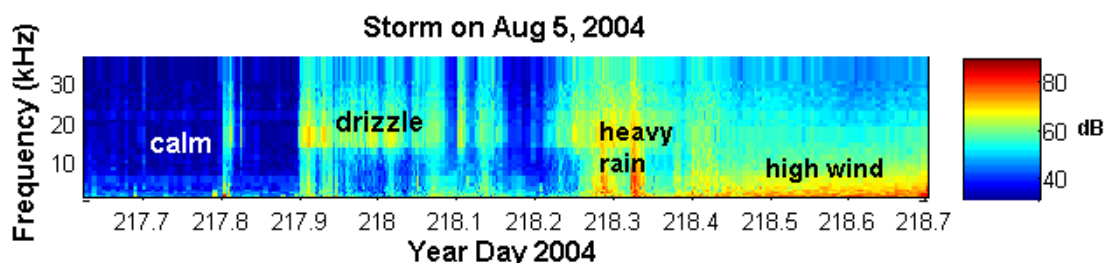


Figure 2. *The underwater acoustic record of a storm passing on August 5, 2004 (Year Day 218) at the M2 mooring in the Bering Sea. [The colorized units for sound intensity are in decibels (dB) relative to $1 \mu\text{Pa}^2\text{Hz}^{-1}$.]*

Figure 2 shows an example of the underwater acoustic record of a storm passing the M2 mooring on Aug 5, 2004. The record is interpreted as a period of calm, followed by drizzle, heavy rain and finally high winds as a strong atmospheric front passes over the mooring location. This interpretation is possible because different physical sea surface processes such as wind wave breaking and raindrop splashes have characteristic underwater sound spectra that allow the processes to be detected and quantified (Ma and Nystuen, 2005). Other sounds are also present, including shipping, sonar or other human noises, and biological sounds such as cetacean calls and clicking. Again, these other sounds have temporal and spectral characteristics that allow them to be identified. In turn, these sounds can be used to detect, identify and census marine animal populations (e.g. Moore et al., 2006).

WORK COMPLETED

Three active/passive acoustic instrumentation packages have been acquired by ARL/PSU (Miksis-Olds). Two existing PALs from APL/UW (Nystuen) were refurbished and deployed during the first year. Data have been collected from both mooring sites, and a year of PAL data from previous deployments at M2 and M5 have been incorporated into the data analysis effort. In particular, two full years of PAL data from M5 (2007-2009) are available for this effort. New PALs have been fabricated and are currently deployed at both mooring sites.

Initial analysis has been performed on the PAL data from 2007-2008 at M5, and PAL data from summer 2004 and fall 2008 at M2 have been analyzed. The PAL data from 2004 have been prepared into a refereed manuscript (Nystuen et al. 2009, submitted).

RESULTS

One interesting feature of the mooring at M5 is coverage of the mooring location by sea ice during part of the year. These data represent a first sampling of this environment during the winter season. Figure 3 shows a summary of marine mammal detection during this season and shows a high correlation of animal presence with sea ice coverage. In particular, the short time series from the PAL were used to identify the mammals present. Bowhead whales choruses started as soon as ice began to form, and ended as they migrated northward in April. Ice seals (Bearded & Ribbon, and Walrus) began calling as the pack ice appeared and ended as it disappeared. These animals were not detected at other times of the year, indicating a seasonal utilization of this environment.

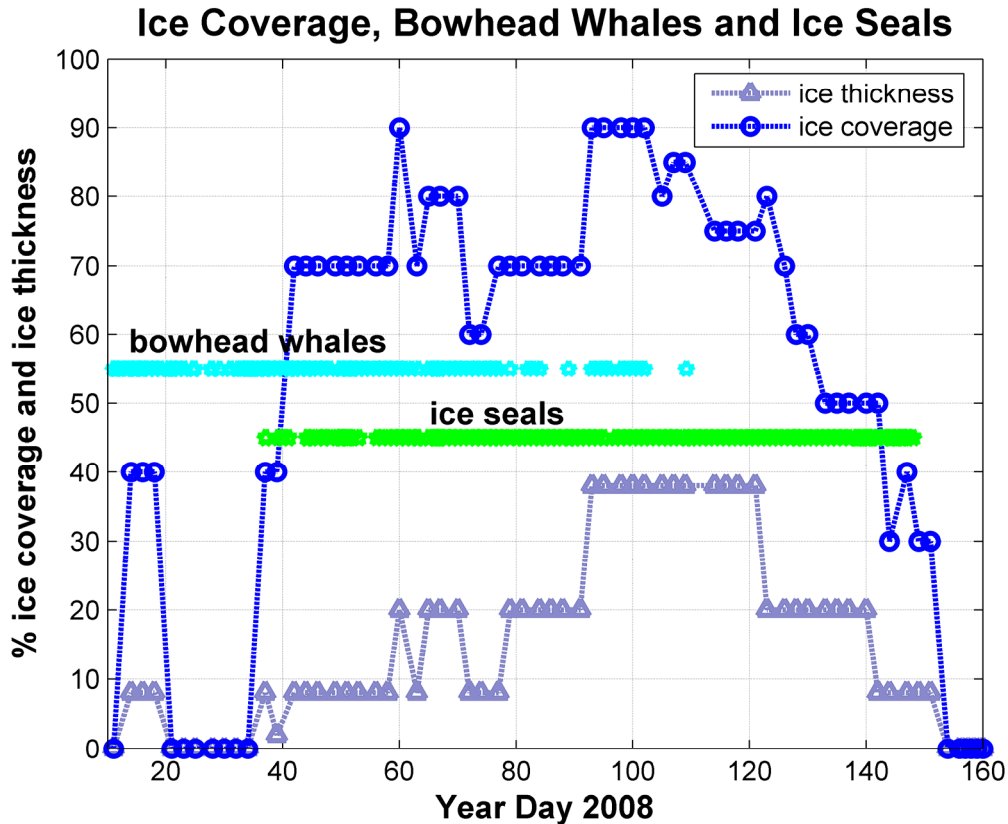


Figure 3: Sea ice coverage and animal presence at M5 during the winter of 2008. Bowhead whales begin calling as the ice appears. The ice seals (Bearded & Ribbon Seals and Walrus) are present when the ice is thicker and more extensive. Neither group is detected at other times of the year when open water is present. The short time series collected by the PAL were used to identify which animals are present and when.

Another initial goal is to identify different acoustic signals associated with ice cover. In particular, can sea ice be detected using passive acoustics? In addition to having this knowledge available to help interpret the biological data, this objective is also important because identifying ice free cover will allow sub-surface instrumentation platforms, including drifters, sea gliders and moorings, to surface in safe conditions (not ice) and report data to users. Thus, this objective is of interest to many users outside of the marine mammal community.

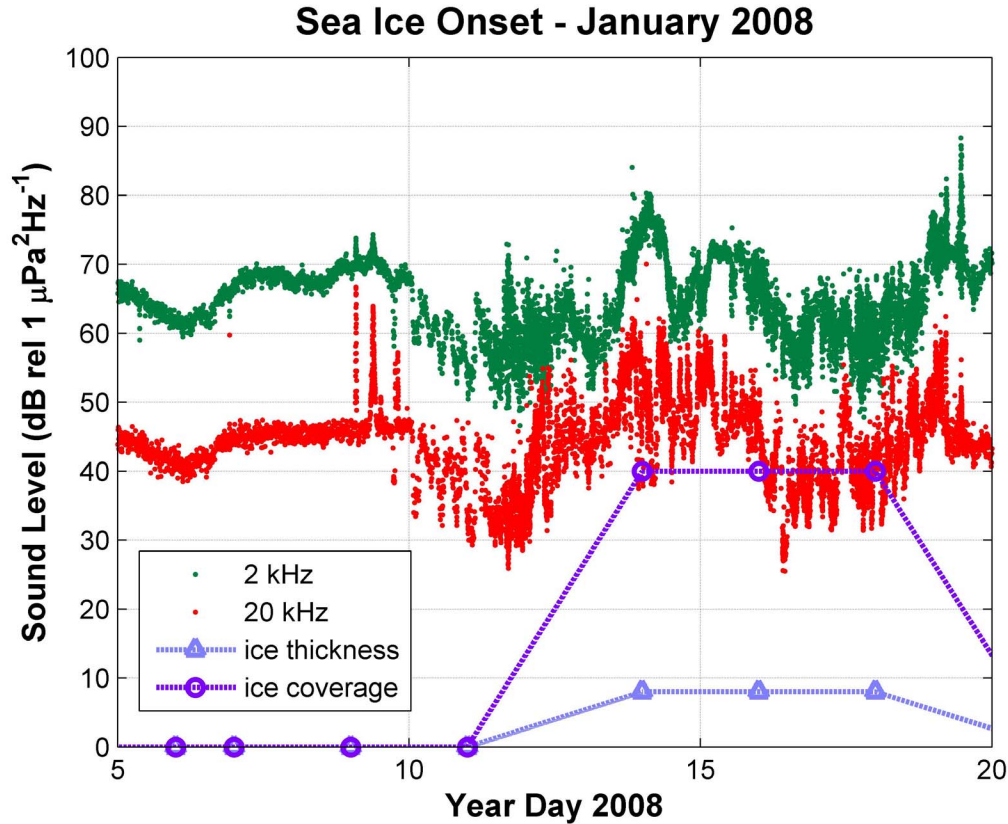


Figure 4. *The acoustic record at 2 and 20 kHz during the onset of sea ice at M5 in January 2008. An increase in short temporal variability of sound levels is apparent as sea ice is detected by satellite sensors.*

Figure 4 shows that the acoustic signal as sea ice cover forms or moves over the M5 mooring in the central Bering Sea. The temporal character of the acoustic record changes, and contains much higher short temporal variability. At the lower frequencies (< 5 kHz) the increase is due to calling bouts from marine mammals, in this case, Bowhead whales. At the higher frequencies, the animal sounds are less ubiquitous and are mostly associated with physical processes, such as ice forming, cracking or melting. Apparently, these processes have different time scales than the wave breaking in open water that is closely correlated to wind speed.

In addition to different time scales, the physical processes also have unique spectral signatures. This is especially important for monitoring from a low duty cycle instrument such as the PAL because the PAL uses adaptive processing to sample different processes in the environment. This decision regarding which sampling strategy to use depends on an objective on-board analysis of the spectral character of the sound.

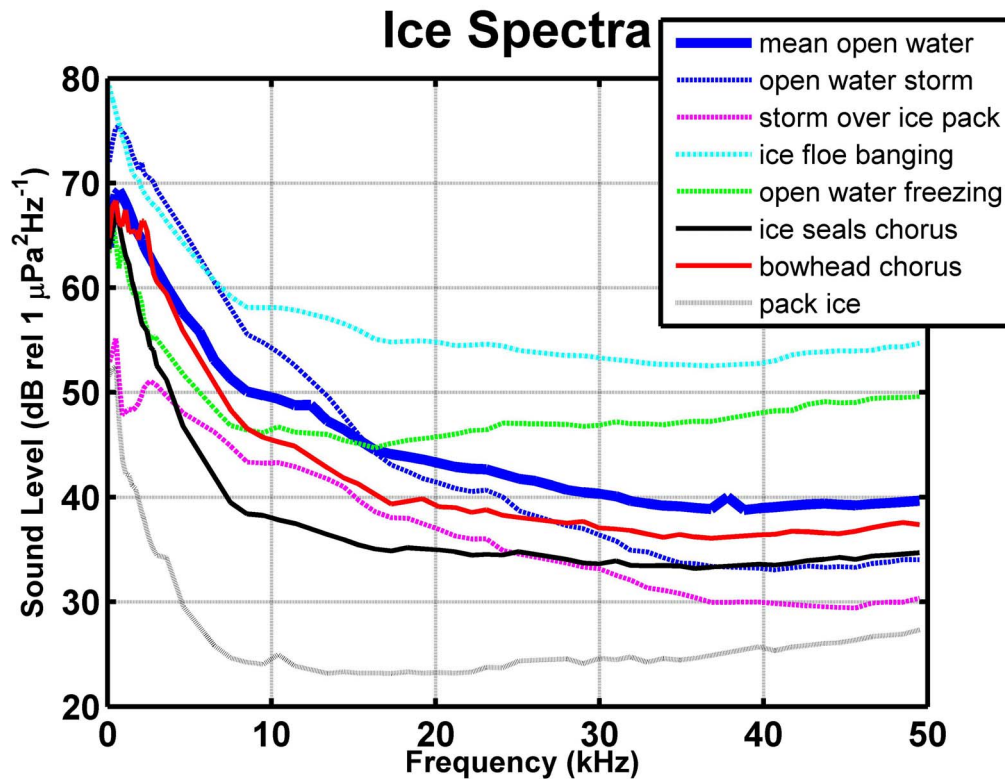


Figure 5. Typical (type) acoustic spectra associated with different sea ice conditions. The mean open water spectrum is shown for comparison. Differences from the open water spectrum allow ice coverage to be identified and classified.

The ice-covered environment has many distinctive spectra associated with different ice processes (Fig. 5). In general, recorded spectra at the M5 site, change rapidly from one of these spectral types to another at the scale of changing surface conditions (hours to days). The mean open water spectrum is shown for comparison. The amplitude of this spectrum can be used to quantify wind speed (± 0.4 m/s). The previously reported type spectrum associated with storm conditions (wind speed > 10 m/s) over open water is also shown. In this situation, ambient bubble clouds absorb sound at higher frequencies (> 10 kHz) causing the recorded spectral levels to actually be lower than the spectral levels at lower wind speeds.

The ice spectra shown in Fig. 5 have not been previously reported. These include the sound of open water freezing (showing a broadband high frequency component increasing in amplitude above 20 kHz), loud floe noise (likely associated with ice floes banging on one another), very quiet conditions associated with fast pack ice, and spectra associated with storms over pack ice (showing relatively lower levels at low frequency). Two ubiquitous sets of animals also produced distinctive spectra – bowhead whales and ice seals (Bearded & Ribbon Seals and Walrus). These animals do not produce much sound above 5 kHz, and so most of the higher frequency data are from physical processes rather than animals. Note that some animals do utilize the higher frequency bands, e.g. killer and beluga whales, but these animals are only occasional visitors at this site.

An objective classification is achieved by multivariate analysis where the multiple variables used are sound levels at particular frequencies or spectral slopes that identify unique features of the sound. Figure 6 shows a multivariate analysis that sorts the spectra shown in Fig. 5 into classified sounds. Clustering of points shows that the physical conditions “open water freezing”, “floe banging”, “open water storm” and “pack ice” are separable when comparing sound levels at 8 and 20 kHz, but “storm over ice pack” is not identified. However, when comparing 8 and 2 kHz, this condition is detectable, but “open water freezing” is not. And calling bouts from bowhead whales and ice seals is detected when comparing 8 and 2 kHz, but not 8 and 20 kHz. This is reasonable as these animals do not produce much sound above 5 kHz.

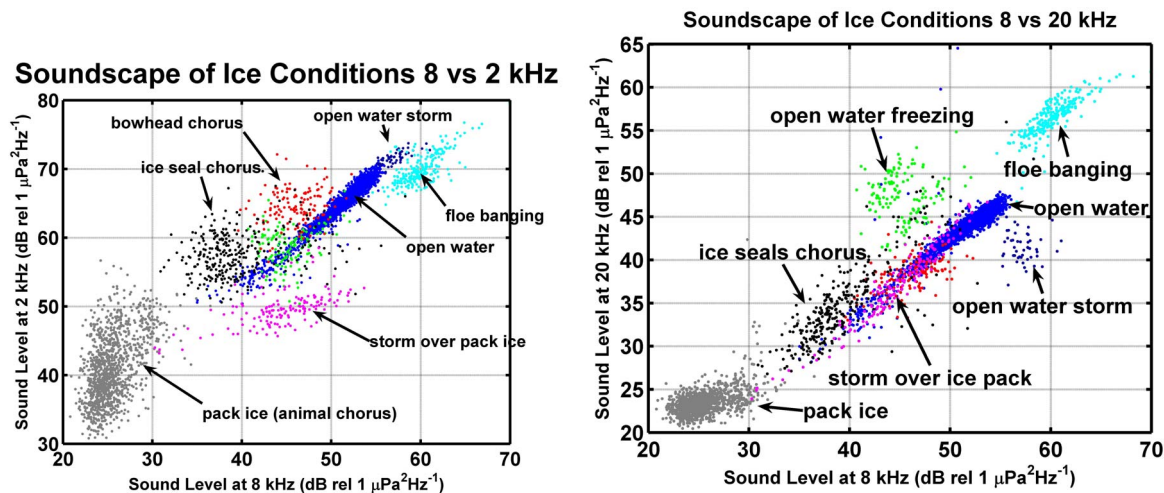


Figure 6. Multivariate analysis to identify surface conditions from ambient sound. The left panel shows a comparison of sound levels at 8 and 2 kHz, while the right panel shows a comparison of sound levels at 8 and 20 kHz. Eight classifications of sound (Fig. 5) are identified by clustering of points on these soundscape diagrams.

IMPACT/APPLICATIONS

The acoustic measurement system used in this project has the advantage of being deployed for long periods of time on subsurface moorings, affording the opportunity to collect valuable data during the harsh conditions of the winter season when traditional sampling techniques are not possible. The combination of year-round acoustic data collected with the active-passive acoustic system, hydrographic data collected by NOAA mooring sensors, and biological samples collected during each research cruise afford the opportunity to apply the acoustics to a large spectrum of scientific questions.

The passive identification of ice types present has applications outside of the marine mammal community. In particular, by identifying the presence or absence of surface ice, remote oceanographic instrumentation platforms, including drifters, sea gliders and sub-surface moorings can be allowed to surface in safe conditions (no ice) and report data back to users. This will allow potential data collection in remote ice-covered regions where data collection is sparse, and thus greatly expand knowledge of these environments.

The system used in this study is appropriate for use in almost all marine environments. It provides an advantage over continuous recording instruments in that the initial real-time processing of

environmental sound by the PALs detect and identify sources of interest without an overwhelming amount of data needing post-processing.

TRANSITIONS

Underwater ambient sound contains quantifiable information about the marine environment, especially sea surface conditions including wind speed, rainfall rate and type, and sea state conditions (bubbles), and now, the presence or absence of sea ice. Mostly this information is unused by oceanographers and the Navy. This project represents a transition from the study of ambient sounds themselves into the application of the physical environment inferred from the ambient sound as an aid for the interpretation of other types of data collected in the same environment. This is a fundamental advance for practical use of passive acoustic monitoring of the underwater marine environment.

RELATED PROJECTS

The ONR-supported project “Monitoring sea surface processes using high frequency ambient sound”, N00014-04-1-099, has as its principal goal to make passive acoustic monitoring of the marine environment an accepted quantitative tool for measuring sea surface conditions (wind speed, rainfall and sea state), monitoring for the presence and identity of marine wildlife (especially whales), and monitoring anthropogenic activities including shipping, sonar and other industrial activities. The new effort described here builds on the research of this project.

Several NOAA-supported projects, including Passive Acoustic monitoring of killer and beluga whales at the Barren Islands, Alaska, the Bering Sea Acoustic Report, Marine Mammal Monitoring for NW Fisheries, and Monitoring killer whale predation at Stellar Sea Lion rookeries in the Aleutian Islands, use PALs as the principal monitoring instrument for the description of the environment and for the detection and identification of marine cetaceans and other marine animals. This project benefits directly from the data collection strategies and interpretation developed for these projects.

REFERENCES

Ma, B. B. & Nystuen, J. A. (2005). Passive Acoustic Detection and Measurement of Rainfall at Sea. *J. Atmos. and Oceanic Tech* 22, 1225-1248.

Moore, S.E., Stafford, K.M., Mellinger, D.K. & Hildebrand, J.A. 2006: Listening for large whales in the offshore waters of Alaska. *Biologist's Toolbox* 56, 49-55.

Nystuen, J.A., M.B. Hanson and C. Emmons, 2007: “Listening for killer whales in the coastal waters of the NE Pacific Ocean”, 2nd International Underwater Acoustic Measurements Conference, Heraklion, Crete, June 2007.

Nystuen, J.A., S.E. Moore and P.J. Stabeno, 2009 “A sound budget for the southeastern Bering Sea: measuring wind, rainfall, shipping and other sources of underwater sound”, *J.Acoust.Soc.Am.* (submitted).

Stabeno, P.J. and G.L. Hunt, Jr. 2002: Overview of the Inner Front and Southeast Bering Sea carrying capacity programs. *Deep-Sea Research*: 49(26), 6157–6168.